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HEAT TRANSFER STUDIES OF SOLID ROCKET IGNITERS

Engineering Department

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Division of United Aircraft Corporation

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1.0 INTRODUCTION

This is the third quarterly progress report for the twelve month program being conducted at UTC under Contract No. NAS7-302. The program, entitled, "Heat Transfer Studies of Solid Rocket Igniters," was initiated to provide analytical and experimental information on the heat input to a solid propellant grain during the period of time between start up of the igniter and ignition of the propellant surface. The object of the study is to develop techniques for predicting the flow phenomena and heat transfer such that ignition delay may be predicted for new solid rocket motor designs.

The first quarter of work was primarily concerned with the design and procurement of two types of experimental apparatus for use on the program. The first is a flow visualization apparatus which consists of a 3" x 3" x 16" chamber with plate glass sides. This apparatus can be fitted with miniature igniters at the head (closed) or aft (open) end and photographed using either nitrogen as a working fluid or hot solid propellant exhaust products. The apparatus has been used in obtaining schlieren photographs and motion pictures of cold and hot flow tests as well as providing preliminary heat transfer data to a cold wall. Also designed was a copper tube apparatus to provide a full scale model for study of the gas dynamics and the cold wall heat transfer problems.

The second quarter of work involved the setup of the flow visualization tests and some experimental work. Also procurement of copper tube parts was continued.

The third quarter involved the completion of the flow visualization tests and the setup and preliminary firing of the copper tube apparatus. The details of the work are presented in this report. Analysis of the radiant heat transfer was started during the third quarter.

During the fourth quarter the experimental program is expected to be completed. Analysis of the gas dynamics and remaining heat transfer problems will be made during the quarter.

2.0 FLOW VISUALIZATION TESTS

During the third quarter the Flow Visualization Tests were completed. The results of the heat transfer measurements were presented in the sixth monthly progress report (Reference 1).

Movies taken of the firings consistently show the same general variation of the radiation intensity with axial chamber location; namely a bright central region, and a decrease in brightness toward each end of the chamber (except for the localized igniter jet and wall impingement zone). The heat transfer data (Figures 1 and 2 of Reference 1) gives an indication that this radiant energy is significant when compared to the convective flux since local maxima are shown at axial locations of 7.6" and 8.4". These axial locations are near the center (axially) of the flow visualizer chamber. The maximum radiant intensity from particle cloud at constant temperature is predicted to be near the chamber center by the analysis presented in Appendix A to Reference 1.

A post fire inspection of the inert propellant slabs which had been placed in the flow visualizer chamber opposite the heat transfer surface provided some interesting data. These slabs were placed in a position such that one of the jets from the canted nozzle igniter impinged directly on the inert propellant surface. The slab subjected to impinging flow of non-aluminized igniter gasses eroded at an average rate of .20±25% inches per second, directly under the igniter jet. The slab subjected to the aluminized igniter gasses eroded at an average of .40±25% inches per second. Both runs had an average chamber pressure of about 20 psia. These erosion rates are higher than propellant burning rates at comparable low pressures. It seems reasonable, therefore, to suspect that the igniter mass flow is augmented by evolution of burning pieces of propellant from the igniter impingement zone before significant flame propagation has taken place. Also the alumina particles from both the igniter and the eroded propellant contribute to a high radiative heat transfer to the unignited propellant surface downstream.

3.0 COPPER TUBE TESTS

During the third quarter the copper tube apparatus was set up and fired at the UTC development site, Coyote, California.

Figure 1 is a sketch of the test cell and apparatus. The test cell is a 6' by 8' concrete room, open on one 8' side. An instrumentation room is attached which is 6' x 6' and houses the recorder, calibration circuitry, ignition circuit, etc. The copper tube is oriented on a steel stand such that the exhaust gasses are aimed out of the cell.

A trial run was set up for checkout of the instrumentation performance. Pressure transducers, radiation gages, backside thermocouples and a surface thermocouple were included in the checkout. Although the data from this run has not yet been reduced, the convective and radiative heat flux and the pressure data appear to be in the range expected.

The pressure transducers are 100 psi taber units used in a standard installation. They presented no new problems.

The radiation gages are slug type calorimeters, developed and calibrated at UTC. A sketch of the installation is shown in Figure 2. The instruments are placed at six axial stations along the duct. In order to prevent the protective quartz windows from being fouled by the igniter gasses, a nitrogen purge system was set up. The nitrogen is turned on 2 seconds before ignition and runs during the igniter action time. The intent of the system is to thicken the boundary layer over the windows so much that no alumina or exhaust soot particles can collect. The effect of the nitrogen on the radiation heat flux is negligible and the effect on the convective heat transfer to the radiation gages is beneficial, because of the thickened and cooled boundary layer. Since the convective heat transfer measurements are taken in locations several inches away from the radiation gages, no detrimental effect on these measurements is expected from the nitrogen purge. No further change to the radiation measurement system is expected during this program.

Thermocouples placed on the outside surface of the copper tube as shown in Figure 3 were recorded during the test. A common copper leadout was brought to the recording equipment. Each Constantan wire was joined to a copper wire in an insulated reference junction box and the potential difference between each of these leadout wires and the common copper lead was recorded. The reference junction box temperature was also recorded. No change in the copper tube outside thermocouples is anticipated during the remainder of the program.

The surface thermocouple used in the checkout firing did not perform satisfactorily. A post fire inspection showed that all of the nickel coating on the surface element had been removed. Efforts to perfect this instrument will continue, but not at the expense of the test schedule.

4.0 ANALYSIS

During the third quarter an analysis was made on the wall heat transfer due to a cloud of radiating particles contained in a finite cylindrical duct. Data from the copper tube tests will be compared with the heat transfer predicted by the analysis. As previously stated, the heat transfer trends and the radiation intensity variation seen in the flow visualization tests are in agreement with the analysis.

A gas dynamics analysis will be undertaken during the fourth quarter. Particular attention will be given to predicting the velocities in the impingement zone. A method of characteristics program is available and will be used to predict the free jet core velocity distribution. A mixing zone analysis is expected to complete the definition of the flow field.

The heat transfer analysis will include work in the recirculation, impingement zones and in the fully established flow channel for the head end igniter configurations.

Pressure and heat transfer measurements will be made available by the copper tube tests for correlation with the analysis. An analysis of the gas dynamics and heat transfer for the aft igniter configurations will also be attempted.

REFERENCES

1. Mullis, B. G., Heat Transfer Studies of Solid Rocket Igniters, Monthly Progress Report No. 6, February 1965.

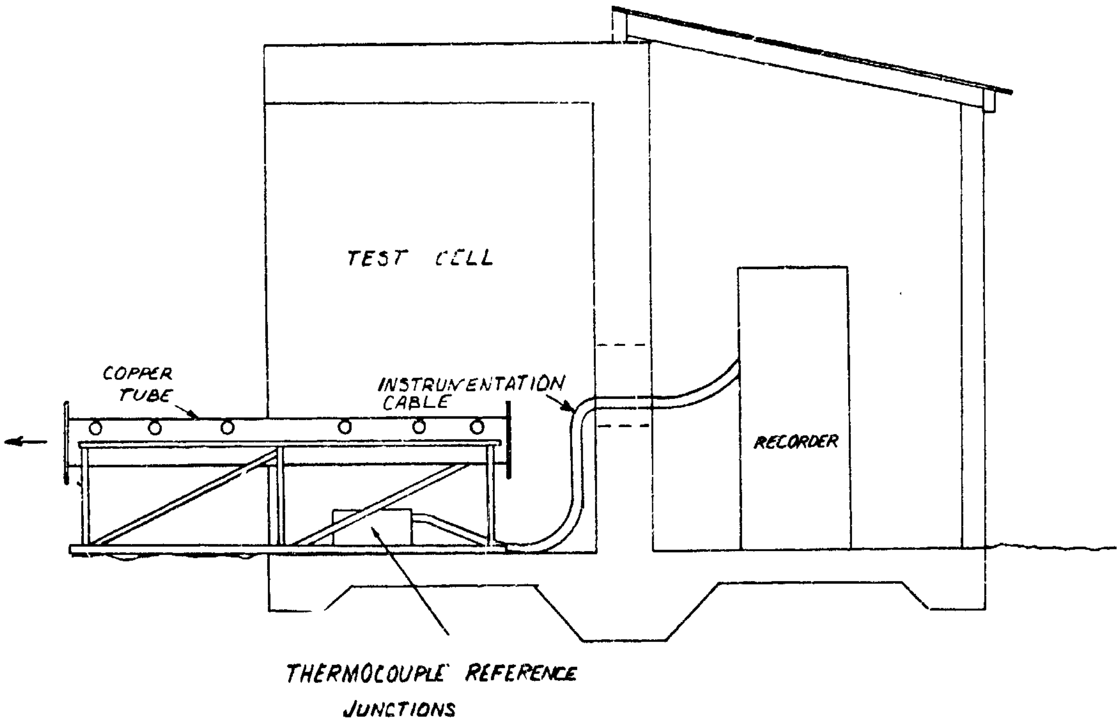


FIGURE 1

TEST CELL - SETUP FOR COPPER TUBE TEST PROGRAM

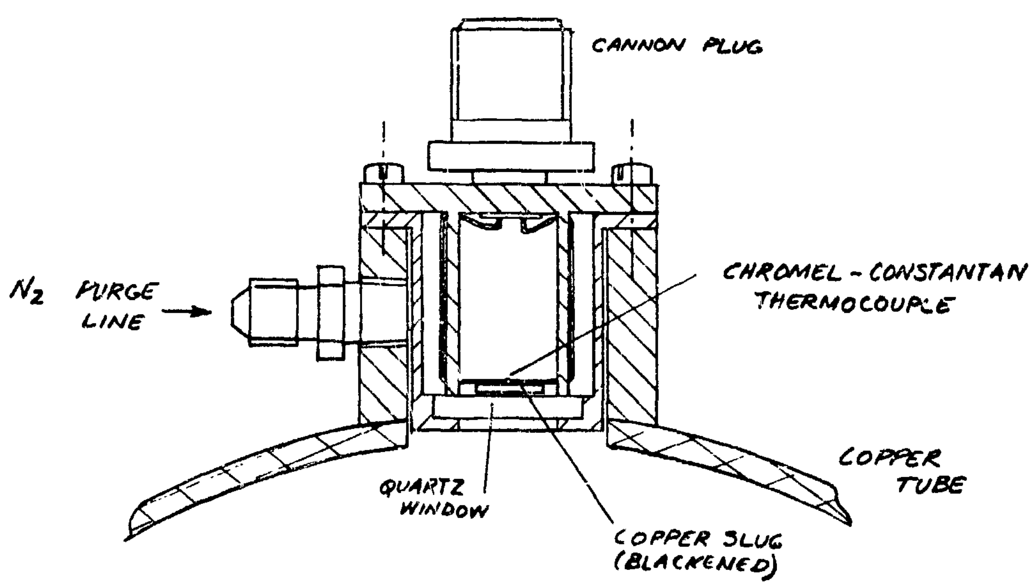
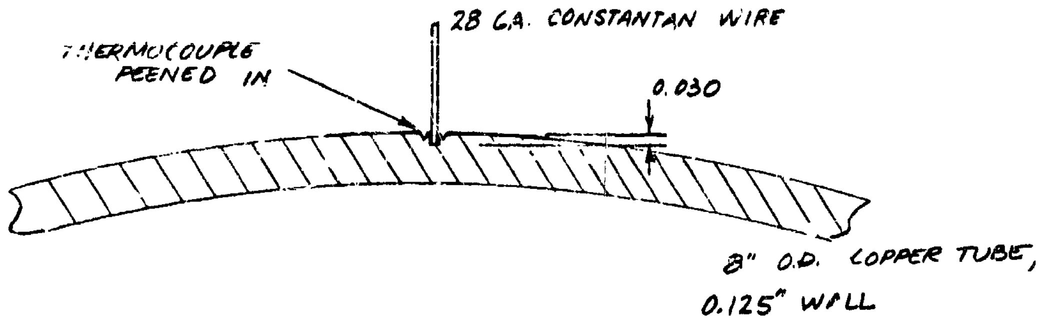


FIGURE 2

UTC'S RADIATION CALORIMETER



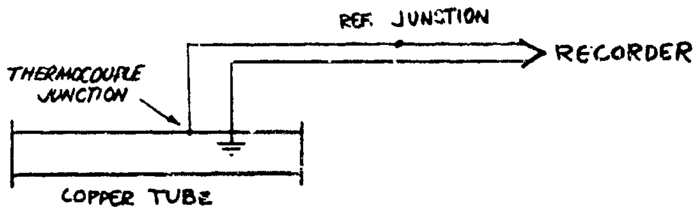


FIGURE 3

COPPER TUBE THERMOCOUPLE INSTALLATION